

Microlens Fabrication by the Modified LIGA Process

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ABSTRACT

A microlens or microlenses array has been fabricated by a novel fabrication technology which is based upon a deep X-ray exposure and a thermal treatment of a resist, usually PMMA. The fabrication technology is very simple and produces the microlenses array as well as the microlens which has good surface roughness less than 1 nm. Molecular weight and glass transition temperature of PMMA is reduced when it is exposed to the deep X-ray. The microlens is produced through the effect of surface tension and reflow by applying the thermal treatment on the irradiated PMMA. A configuration of the microlens is determined by parameters such as absorbed X-ray dose on PMMA, heating temperature, and heating time in the thermal treatment. Diameters of the produced microlens range from 30 μm to 1500 μm and their heights vary between 10 μm and 25 μm .

INTRODUCTION

A number of new microfabrication processes have been developed for realization of microsystems principally devoted to micromechanical and micro-optical applications. One of these microfabrication techniques is the LIGA process (German acronym for lithography, electroforming, and moulding), which is particularly well suited to manufacture microdevices with high aspect ratio. It was developed at the Karlsruhe in Germany for nuclear research experiments in the early 80s [1]. A deep X-ray used as a source in the LIGA process is much stronger than other light sources and enables us to fabricate multi-shape structures in submicrometer degree.

A microlens has emerged as an essential component in optical communication, optical storage system, display system, and biomedical instrument. A lot of researchers tried to fabricate the microlenses by manifold processes such as modified LIGA process [2], photoresist reflow process [3], micro intrusion process [4], and isotropic etching process [5]. Nevertheless, most of them seem not to be successful because of complexity in the fabrication process and difficulty in realizing microlenses array.

A group of Institute of Microtechnology (IMT) in Germany reported a fabrication technology of microlens with a modified LIGA process in 1997 [2]. The process is based upon characteristic change of glass transition temperature (T_g) of polymer exposed by a deep X-ray,

which is composed of the first X-ray exposure on PMMA, development, the second X-ray exposure, and thermal treatment as shown in Fig. 1. However, the approach seemed to be somewhat complicated in terms of the fabrication process.

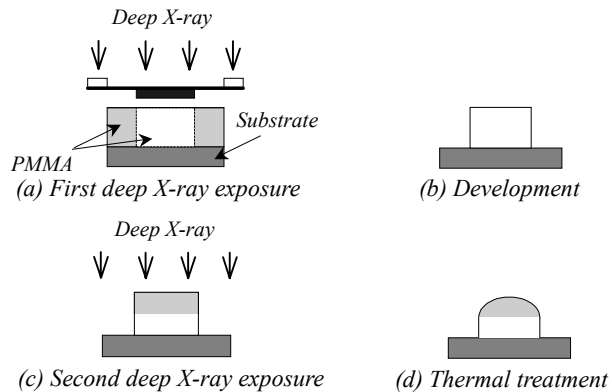


Fig. 1 Previous fabrication processes of the microlens at IMT.

In this paper, we present a relatively simple fabrication technology of a microlens or microlenses array which consists of "a" deep X-ray exposure and "a" thermal treatment.

Concept of the microlens fabrication process is illustrated in Fig. 2. Molecular weight of X-ray exposed polymer in PMMA is reduced when it is exposed to the deep X-ray [6]. The glass transition temperature (T_g) of exposed PMMA is reduced because it is related to the molecular weight. The microlens or microlenses array is produced by the effect of surface tension and reflow in the thermal treatment on the irradiated PMMA. Shape of microlens is determined according to absorbed dose on PMMA, diameter of microlens, heating temperature, and heating time in the thermal treatment.

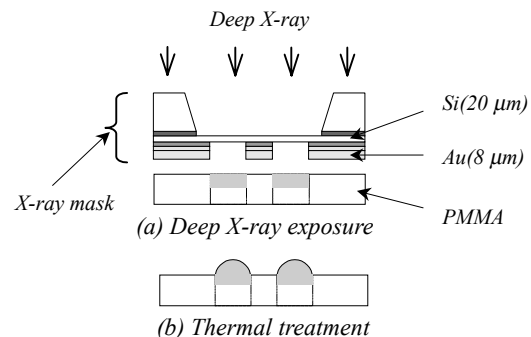


Fig. 2 New fabrication processes of the microlens at POSTECH.

FABRICATION

Fabrication of an X-ray Mask

Fig. 3 shows a fabrication process of X-ray mask used for realizing the microlens or microlenses array.

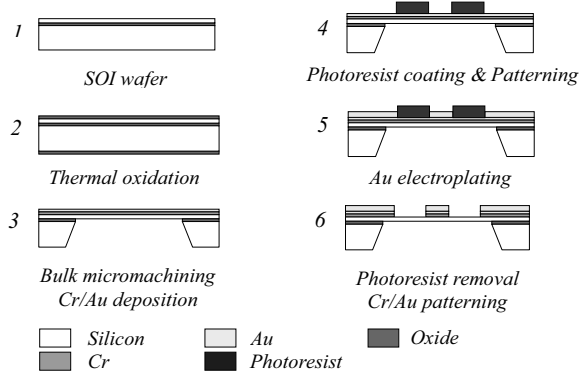


Fig. 3 Fabrication sequences of an X-ray mask for the microlens.

The process starts with 4 inch, N (100), and 20 $\mu\text{m}/1 \mu\text{m}/400 \mu\text{m}$ SOI wafer. 1 μm thick thermal oxide is grown at 1050 $^{\circ}\text{C}$ as a passivation layer. An anisotropic wet etching of the silicon wafer backside of is performed in 20 wt% TMAH solution at 90 $^{\circ}\text{C}$ for 8 hours. The layers of remaining oxide are removed by buffered HF to get the 20 μm thick silicon membrane. A 0.1 μm thick gold (Au) layer is thermally evaporated as a seed layer for electroplating after a 0.03 μm thick adhesion layer of Chromium (Cr) is thermally evaporated. A 10 μm thick photoresist AZ 9260 layer is spin coated and patterned for an Au electroplating. Based on this structure, the 8 μm thick Au layer is electroplated as an absorber of X-ray mask at the current density of 2 mA/cm^2 . The remaining photoresist is removed by dipping in acetone and an etching of Au/Cr is followed, which produces the 20 μm thick Si membrane of opening for the microlens.

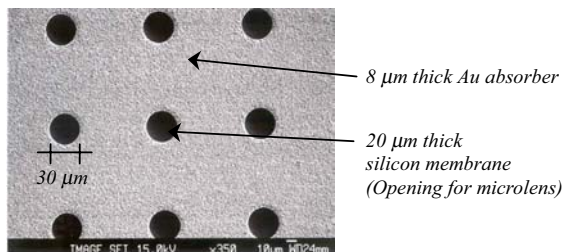


Fig. 4 SEM photomicrograph of the electroplated goldabsorber of the X-ray mask.

Fig. 4 shows a SEM photomicrograph of the X-ray mask which has the 8 μm thick gold absorber with 30 μm diameter apertures on the 20 μm thick Si membrane. The apertures, which will be microlens, have shapes of circular cylinder. The range of microlens diameters is designed from 30 μm to 1500 μm to investigate the size effect caused by the variation of diameters.

X-ray Exposure

The X-ray irradiation is carried out under the operation

conditions of 2.5 GeV energy and 120~170 mA beam current range in the LIGA beamline (9C1) at the Pohang Light Source (PLS) in Pohang, Korea. Fig. 5 shows the schematic view of LIGA beamline system in the PLS.

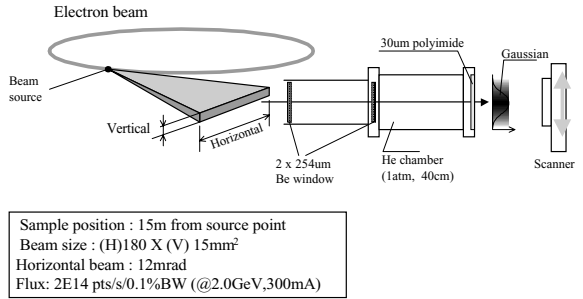


Fig. 5 Specifications of LIGA beamline (9C1) in the PLS.

The top dose of PMMA ranges from 1.14 kJ/cm^3 to 7.76 kJ/cm^3 in the deep X-ray exposure step for investigating the influence of absorbed dose affecting deformation of sample in the thermal treatment. The 2 mm thick PMMA sheets (Goodfellow Inc.), which have T_g of around 95 $^{\circ}\text{C}$, are used as a substrate of the microlens. The polymer chains of exposed PMMA portion are partly broken and its molecular weight is reduced during the deep X-ray exposure. It may result in reduction of T_g of exposed PMMA.

Thermal Treatment

The sample is placed in a convection oven after the deep X-ray exposure (Fig. 2 (b)). The upper part of microstructures partially melts due to the different T_g according to the absorbed dose distribution in the vertical direction. It causes reflow of the upper part, which takes on a configuration of microlens due to surface tension. Fig. 6 shows results of surface profile changes with a Alpha-step 200 Profilometer at different temperature. The height of microlens is increased as the heating temperature is elevated as shown in Fig. 6.

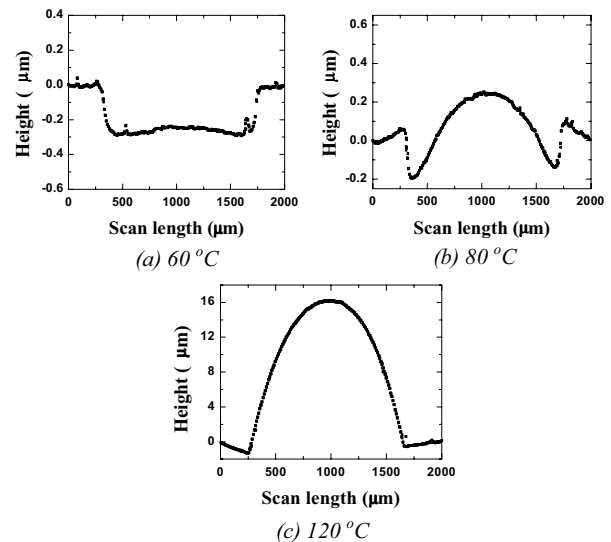


Fig. 6 Microlens profiles at different heating temperature (heating time = 5 min).

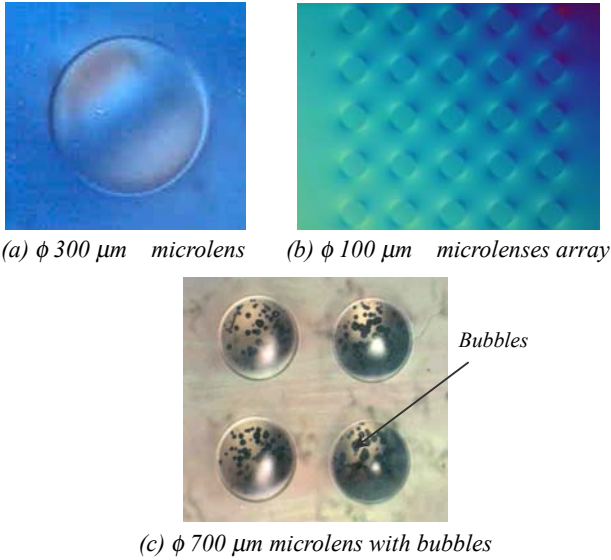


Fig. 7 Microlenses fabricated by melting the deep X-ray irradiated pattern exiting in the PMMA substrate.

Actually fabricated microlenses are shown in Fig. 7. The microlenses in Fig. 7 (a), (b) are fabricated under the conditions of heating temperature of 120 °C, heating time of 7.5 min, and top dose of 2.4 kJ/cm³. One of methods for increasing changed height is to elevate the heating temperature. However, we can observe the phenomenon that there exists bubbles in the microlens pattern as the heating temperature is excessively elevated over T_g as shown in Fig. 7 (c). It seems to be caused by the fact that the polymer, having the low glass transition temperature in the microlens pattern, is boiled at high temperature.

EXPERIMENTS AND RESULTS

It is important to know what are main parameters in microlens fabrication process in order to design the configuration of microlens. It is revealed by experiments that the shape of microlens depends mainly on the top or bottom dose on PMMA, the diameter of the microlens, the heating temperature, and the heating time. A substrate for the microlens is a 2 mm thick PMMA sheet and its physical and thermal properties are very important with a view to gaining well optical traits and large deformation for the microlens. The PMMA has T_g of 95 °C, linear expansion coefficient of $7 \times 10^{-5} \text{ K}^{-1}$, and refractive index of 1.49. It is possible to design the shape of microlens from these data.

It is repeated in the thermal treatment step that the X-ray irradiated samples are inserted into a forced convection oven, heated at fixed temperature during heating time, drawn out, and measured using the profilometer after they are cooled into normal temperature. The experiments are almost carried out in the temperature range of 60 °C ~ 125 °C.

Absorbed dose on PMMA is a main parameter for determining the configuration of microlens. The glass transition temperature (T_g) may be lowered as the exposure dose increases. It is necessary that the influence of dose is known and optimized for designing

the microlens. The 2 mm thick PMMA is thermally treated under the conditions of the top dose range from 1.14 kJ/cm³ to 4.17 kJ/cm³. The changed height of the microlens as a function of absorbed dose is shown in Fig. 8. The heating time is 4 minutes and the heating temperature is 120 °C. The changed height is measured in 15 minutes after the sample is drawn out from the convection oven. Fig. 8 shows the facts that the microlens is not deformed largely in the case of relatively low or high top dose. The microlens with low top dose cannot be deformed highly because its top portion does not melt even enough at relatively high temperature. In addition, bubbles may be created so easily at the low temperature in the sample with the high top dose. The maximum height may be gained at the range between 2 kJ/cm³ and 3.5 kJ/cm³.

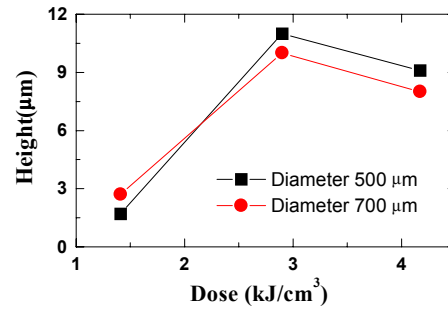


Fig. 8 Curvature of the microlens with top dose (heating time = 5min).

The microlens is fabricated in the diameter range from 30 μm to 1500 μm in order to see the effect of size. A 2 mm thick PMMA is thermally treated under the conditions with the top dose of 2.4 kJ/cm³, the bottom dose of 0.5 kJ/cm³, the heating time of 5 minutes, and the measuring temperature of 120 °C.

The changed height of microlenses is supposed to have nothing to do with their diameters. However, it is expected that capillary force acts on the exposed part when the flexible part shrinks due to the temperature difference after the microlens in the thermal treatment is drawn out from the convection oven. By the way, the smaller the diameter is, the more strongly the capillary force may work. Fig. 9 explains the above considerations well. First, the microlenses with the diameters below 300 μm cannot show the high deformations. Amazingly, the measured value is negative in the microlens with the diameter of 50 μm. Second, the changed heights of the microlenses with the diameters over 500 μm don't give the extraordinary difference between them.

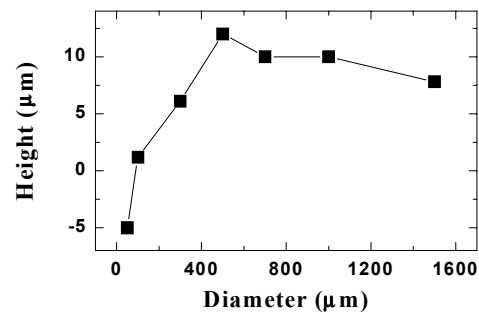


Fig. 9 Curvature height of the microlens with deep X-ray exposure dose.

Fig. 10 presents relations between the changed height of microlens versus the heating temperature and the heating time in the thermal treatment. The top dose of samples is 2.4 kJ/cm^2 , heating time for experiment of heating temperature is 5 minutes, and heating temperature for experiment of heating time is 110°C . Some points may be checked in Fig. 10 (a). The molecular weight of exposed PMMA is reduced when the PMMA is irradiated by the deep X-ray and its volume is lessened. It results in negative value of the changed height at the normal temperature. Deformation begins at 70°C , abrupt change occurs in the heating temperature region over 90°C , and the bubbles are created around 125°C . Fig. 10 (b) shows that curvature height of the microlens gets larger as heating time is longer.

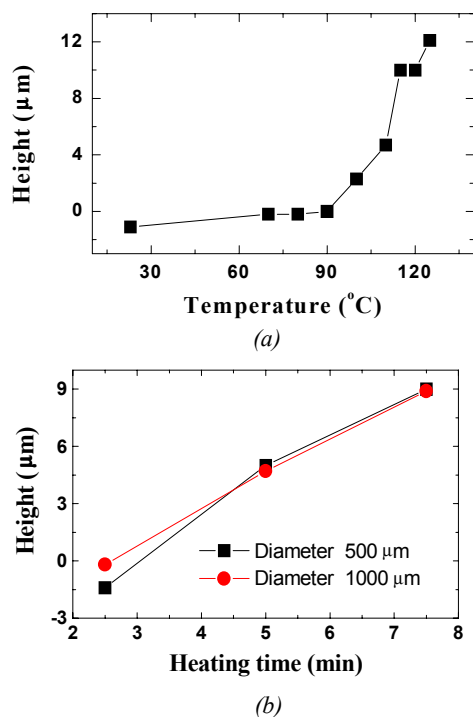


Fig. 10 Curvature height of the microlens with (a) heating temperature and (b) heating time.

The average surface roughness of the microlens measured by an Atomic Force Microscope (AFM; AutoProbe M5, PSIA Co.) is about 0.5 nm and a scanning image is presented in Fig. 11.

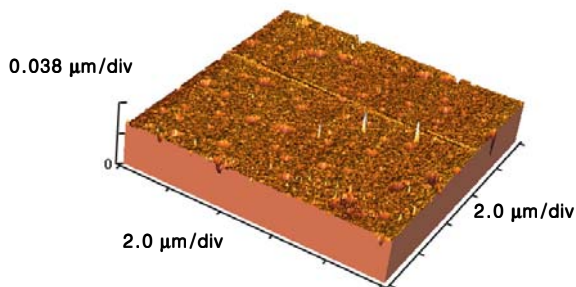


Fig. 11 Scanning image of surface of the microlens measured by an AFM.

CONCLUSION

The microlenses that have the good roughness are

fabricated through the simple steps of the deep X-ray exposure and the thermal treatment without the development of the PMMA. In this research, we have realized not only hemispherical-shaped structure for the microlens but also different structures such as a rectangular-shaped structure, a star-shaped structure etc. with the modified LIGA process. Into the bargain, it is expected to make up an insert mould of a hot embossing or an injection molding process for mass production.

ACKNOWLEDGEMENTS

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